03424-4-S

STATUS REPORT

Period October 1, 1964 to March 31, 1965

FACILITY FORM 602

N65-87657 (ACCESSION NUMBER)	(THRU)
9 (PAGES)	None (CODE)
CR-61469 (NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

NASA Grant NsG-39-60/23-005-002

Entitled

"CAVITATION EROSION PHENOMENA"

ORA Project 03424

By

Frederick G. Hammitt

Laboratory for Fluid Flow and Heat Transport Phenomena
Department of Nuclear Engineering
The University of Michigan
Ann Arbor, Michigan

June, 1965

I. INTRODUCTION

The University of Michigan, Department of Nuclear Engineering cavitation-erosion research program being conducted under NASA Grant NsG-39-60 was approximately on schedule at the conclusion of the report period from the viewpoint of expended funds versus accomplishment, i.e., it appeared that the available funds would be sufficient to complete the presently forseen tasks. However, the effort had been at a lower intensity than had originally been forseen, so that the time period for the completion of this work is somewhat longer than had been anticipated.

During the report period the work under the NASA Grant was strongly complimented by an NSF grant with roughly parallel objectives in addition to contract work for Atomics International which also to some extent paralleled the NASA effort.

The present report follows the form and text of the previous status report (03424-3-S for period April 1, 1964 to September 30, 1964) where these apply. New material is added where applicable.

II. PRESENT OVERALL PROJECT GOAL

The overall program objective for the NASA and NSF grants as well as the Atomics International contract to some extent is broadly to assist the national cavitation research effort to obtain the necessary level of understanding and data to allow optimized designs of turbomachinery and other fluid-flow components from the viewpoints of cavitation performance and damage. Special emphasis is to be placed upon the high-temperature liquid-metal area as applied to SNAP powerplants, etc.

More particularly it is our present minimum goal for the NASA grant to complete the series of venturi* damage runs, both in water and mercury, over a broad range of materials chosen to provide variations of single critical mechanical properties, and to complete the corollary measurements of material mechanical properties, so that correlating parameters relating material mechanical properties to cavitation damage can be delineated. The damage tests in water and mercury are mostly at room temperature, although some tests with 500°F mercury have been made to obtain the effect of the higher vapor pressure.

A parallel program using a vibratory facility has been conducted under the NSF grant wherein it is planned eventually to test most of the same materials tested in the NASA venturi program in the vibratory rig, at the same temperatures attainable in the venturis. In addition, much higher temperature tests are planned in the vibratory facility, still

*The facilities were described in sufficient detail in the previous status report and in numerous other project reports.

with those of the venturi-tested materials which are applicable to such temperatures. Molten lead-bismuth alloy has been chosen for the high-temperature tests, since it offers an approximate "high-temperature mercury", and also is more tractible with respect to handling problems than most other liquid metals. Water and mercury will be used at room temperature, and lead-bismuth and mercury at 500°F (to compare with the mercury tunnel tests at that temperature). At the present writing the full program at 500°F and at 1500°F with lead-bismuth has been completed.

The venturi tests, in addition to exploring a very broad range of material properties as mentioned above, must also examine the effects of fluid velocity, pressures and pressure gradients, effects of geometry in that they perturb the pressures and the velocities (and their symmetry), effects of gas and/or other liquid trace impurities, and fluid temperature (and its effects on vapor pressure, other fluid properties, material properties, etc.), effects of prestressing the materials, etc. Much information and detailed data have been achieved on many of these during the present report period and previously, but much yet remains to be done. For instance, it is necessary to explore single-parameter effects as e.g., the effect of traces of gas and/or water in the mercury, the effect of altering the geometry to the extent of replacing a specimen arrangement comprising two specimens with a 120° separation with either a three-specimen symmetric arrangement or a two-specimen 180° arrangement. All of these have been used in the program, and it has been found that there are apparently substantial differences in damage rates attributable to these relatively minor changes of geometry. At present it is believed that this is due to the non-symmetries introduced by one of the arrangements and the resultant cross-flows which result in small local vortices off the specimen edges. This situation points up the present likelihood that very minor geometrical changes in a flowing system (as opposed to a vibratory system) can change damage rates by orders of magnitude. For example, the substitution of a pin-specimen for a plate specimen in the venturi increased damage rates by several orders of magnitude. This situation is also evident in tests on pumps where vortex-cavitation is often found to be extremely damaging compared to that generated by translatory flows.

In addition to the cavitation tests it has been necessary to conduct a parallel program of mechanical property tests on the various alloys used for the damage tests, at the applicable temperatures, since it was found that handbook values even for very standard materials are not at all sufficient, and that very substantial variations in important mechanical properties occur between different samples of supposedly the same material. This program at the present writing is nearly complete.

It is also desired to examine the cavitation damage by sectioning selected samples to observe effects on the microstructure, and in all cases to examine carefully the damaged surfaces to monitor the type and distribution of pitting. Various special tests have been conducted as, e.g., one in which the microhardness of the cavitated surfaces for several chosen materials was carefully measured before and after various degrees of exposure to cavitation. It has been observed in this particular case that the surface hardness did increase substantially as cavitation proceeded, but as a function of the local intensity of cavitation.

When the data from all of the above have been obtained, it is expected that it will be possible to formulate correlating equations allowing at least the approximate prediction of cavitation damage for flows similar to those investigated as a function of material properties (including prestressing effects), fluid properties (including gaseous and liquid impurity effects), the possible coupling terms between these, and flow parameters such as pressure, pressure gradient, velocity, vorticity, etc. A quite sophisticated, computerized regression analysis is being used to obtain the desired correlating equations, and preliminary indications are that the effort will be successful. It will then be possible to obtain a very direct comparison between the results from the flowing and vibratory (static) facilities, an objective which has been long desired but not yet attained.

In addition, more basic theoretical bubble-dynamic studies have and will be continued. While these of necessity must deal with considerably over-simplified cases, they are capable of allowing a comparison between anticipated damage effects with different fluids and flow conditions, as well as shedding light on the basic mechanisms. For example, a just-completed study of the collapse of a single bubble in an infinite fluid in which all applicable real fluid effects were considered, showed that the pressures generated on a nearby structural member during collapse, were not sufficient generally to cause the observed damage. On the other hand, pressures of damaging magnitude in the vicinity of rebounding bubbles can be shown to exist. It is now planned to investigate the effects of of asymmetries in the collapse which recent experimental and theoretical evidence indicate are likely to be of extreme importance in the actual process.

III. PROGRESS DURING PRESENT REPORT PERIOD

A. Damage Testing in Water Tunnel Facility

The materials involved in the water venturi damage test program were described in detail, along with the reasons for their choice, in the last status report. The water damage test program was continued along the lines set forth in the last status report, and a total of approximately 5670 specimen-hours was accrued during the present report period. The originally planned water damage program is at present nearly complete as is the comparable mercury damage program. However, some special purpose tests remain in both cases.

During the period a new 40 hp variable-speed drive unit was installed on the water facility as the original unit (World War II surplus vintage) failed.

B. Cavitation Performance Testing in Water Facility

In order to obtain the overall correlations previously discussed relating damage to flow parameters it is also necessary to relate cavitation condition to these same flow parameters. Hence investigations involving measurements of pressure profiles along the venturis two-dimensional model, as a function of velocity, fluid, temperature, gas content, etc. have proceeded during the past report period. In addition measurements of local pressures along the test specimen faces themselves, and high-speed motion pictures of the flow have been continued. These tests have been associated with three Ph.D. theses (one of which is now completed) and have been partially supported by the NSF grant, the Atomics International contract, and the NASA grant.

C. Damage Testing in Mercury Tunnel Facility

This program also was described in detail in the last status report, and, during the present report period, has proceeded along the lines so indicated. A total of 2654 specimen-hours was accrued.

D. Performance Testing in Mercury Tunnel Facility

Considerable work similar to that listed above for water facility was conducted during the report period. This is connected with the same Ph.D. Theses.

IV. PUBLICATIONS RESULTING FROM PROJECT WORK

1. "Cavitation Damage Correlations for Various Fluid-Material Combinations", F. G. Hammitt, M. J. Robinson, C. A. Siebert, F. A. Aydinmakine, ORA Report No. 03424-14-T, Laboratory for Fluid Flow and Heat Transport Phenomena, October, 1964

2. "Collapse of a Cavitation Bubble in Viscous, Compressible Liquid - Numerical and Experimental Analyses", R. D. Ivany, F. G. Hammitt, ORA Report No. 03424-15-T, Laboratory for Fluid Flow and Heat Transport Phenomena, April, 1965

3. "Cavitation Bubble Collapse in Viscous, Compressible Liquids - Numerical Analyses", R. D. Ivany and F. G. Hammitt, ORA Internal Report No. 03424-24, Laboratory for Fluid Flow and Heat Transport Phenomena

4. "Cavitation Bubble Observations in a Cavitating Venturi", R. D. Ivany and F. G. Hammitt, ORA Internal Report No. 03424-25, Laboratory for Fluid Flow and Heat Transport Phenomena

5. "Damage to Solids Caused by Cavitation", F. G. Hammitt, Presented at Royal Society Discussion on Deformation of Solids Due to Liquid Impact, May 27, 1965, ORA Internal Report No. 03424-26,

6. "Initial Phases of Damage to Test Spceimens in a Cavitating Venturi", F. G. Hammitt, L. L. Barinka, M. J. Robinson, R. D. Pehlke, and C. A. Siebert, Presented at the Winter Annual Meeting of the American Society of Mechanical Engineers, November 29-December 4, 1964. ASME 64-Wa/FE-2